ILC and CLIC Detector R&Ds

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Tohoku University
12-Nov-09, Muon Collider Workshop, Fermilab

(Much of the contents: from ALCPG09 and CLIC09)

ILC

ILC Features

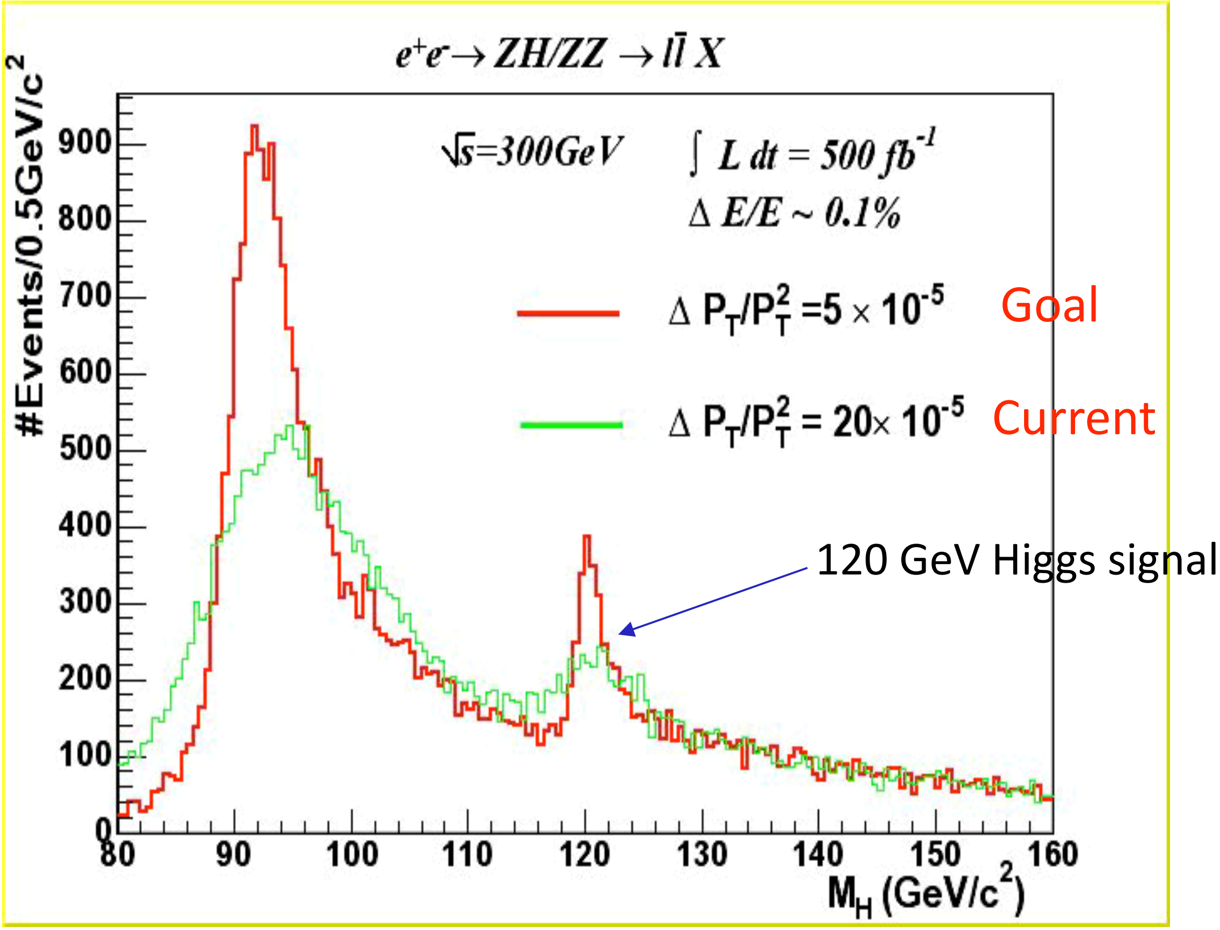
- Well defined initial state
  - e+e- system : 4-momentum known
  - Its polarization(s) also 'known'
- Energy scan
  - e.g. $e^+e^- \to Zh, t\bar{t}$
- Relatively low noise rate (clean!)
- Small beam size, small beampipe (even with pair bkg)

  → Hermeticity, vertex resolution
- Long inter-train gap (200ms) for readout

- Detector can/should take advantage of the above

  → good resolutions

Higgs recoil mass resolution



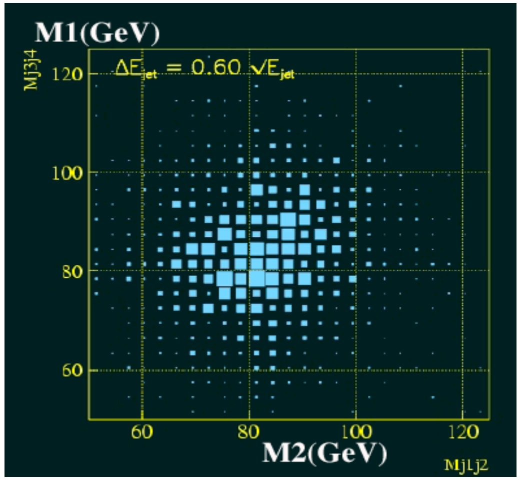
- Good momentum resolution of tracking is required (not a luxury!)

Jet(quark) reconstruction

$$e^{+}e^{-} \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \qquad W/Z \to jj$$

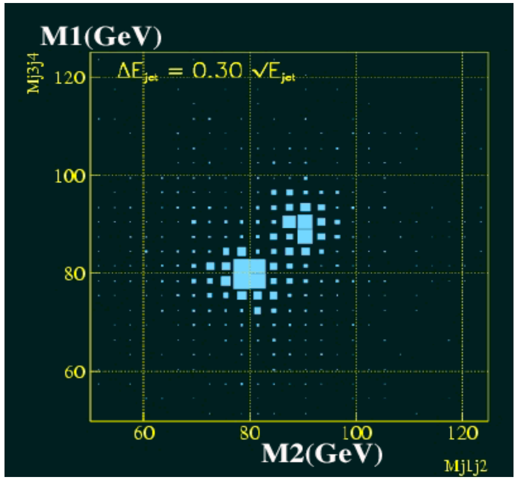
(Important mode if no Higgs is found)

Current



$$\sigma_E / E = 0.6/\sqrt{E(\mathrm{GeV})}$$

Goal

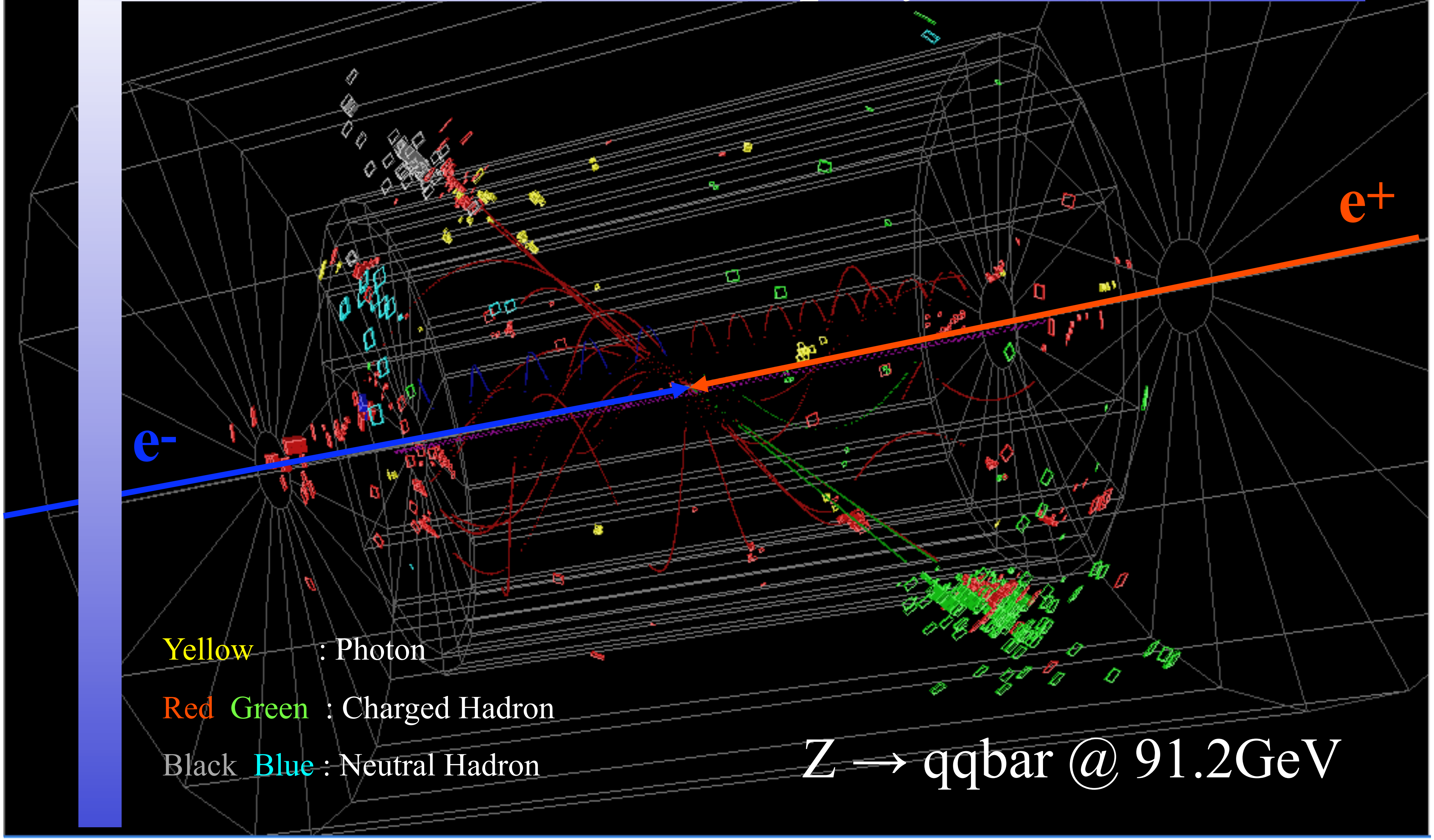


$$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

- $\sigma_E / E = 0.3/\sqrt{E}$ is required for Z/W→jj to be separated (not a luxury!)
- A promising technique : PFA (particle flow algorithm)
  - Use trackers for charged energy, calorimeters for the rest
  - Remove double countings by pattern rec. (granularity!)

PFA Event Display

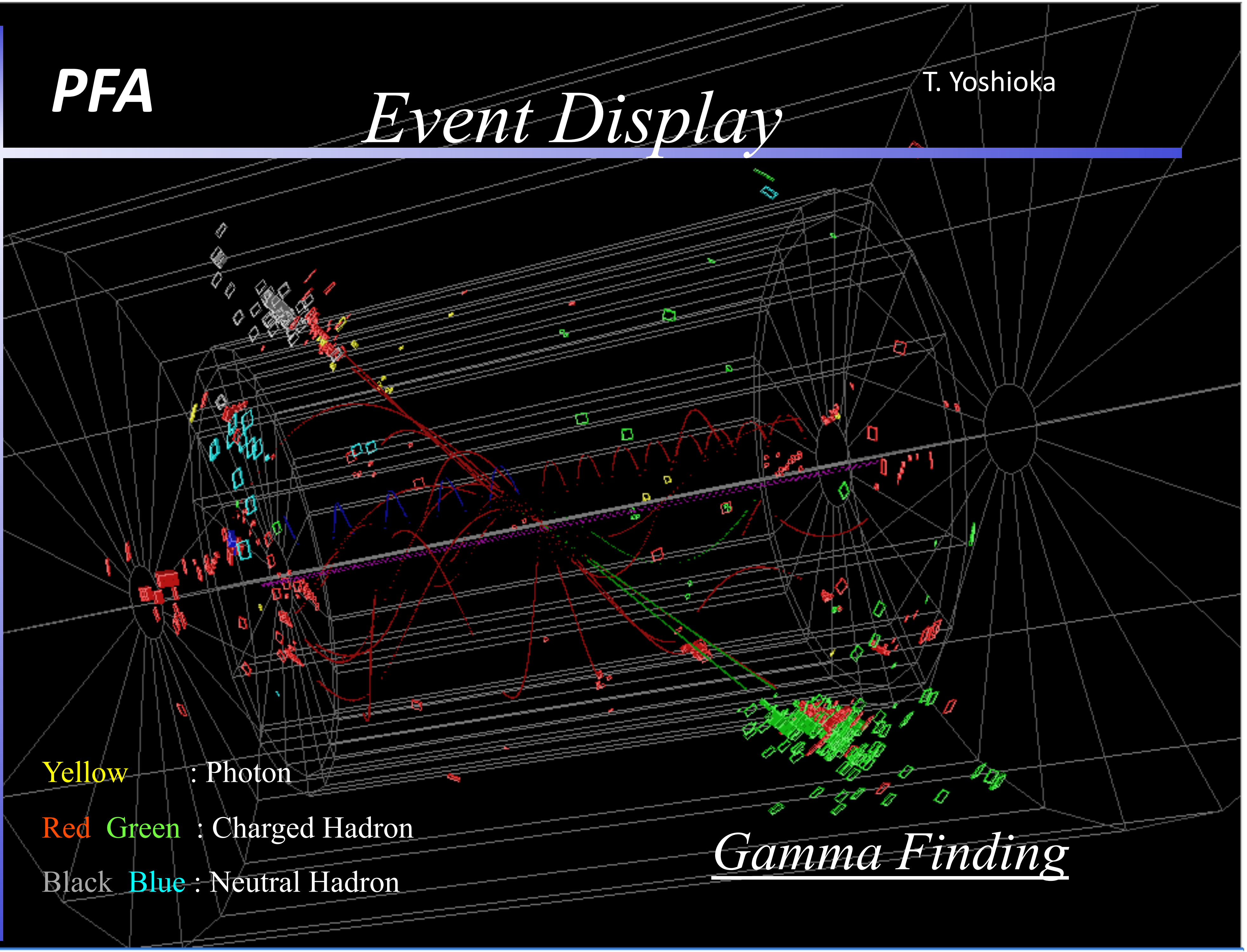
T. Yoshioka



PFA

T. Yoshioka

Event Display



Yellow : Photon

Red Green : Charged Hadron

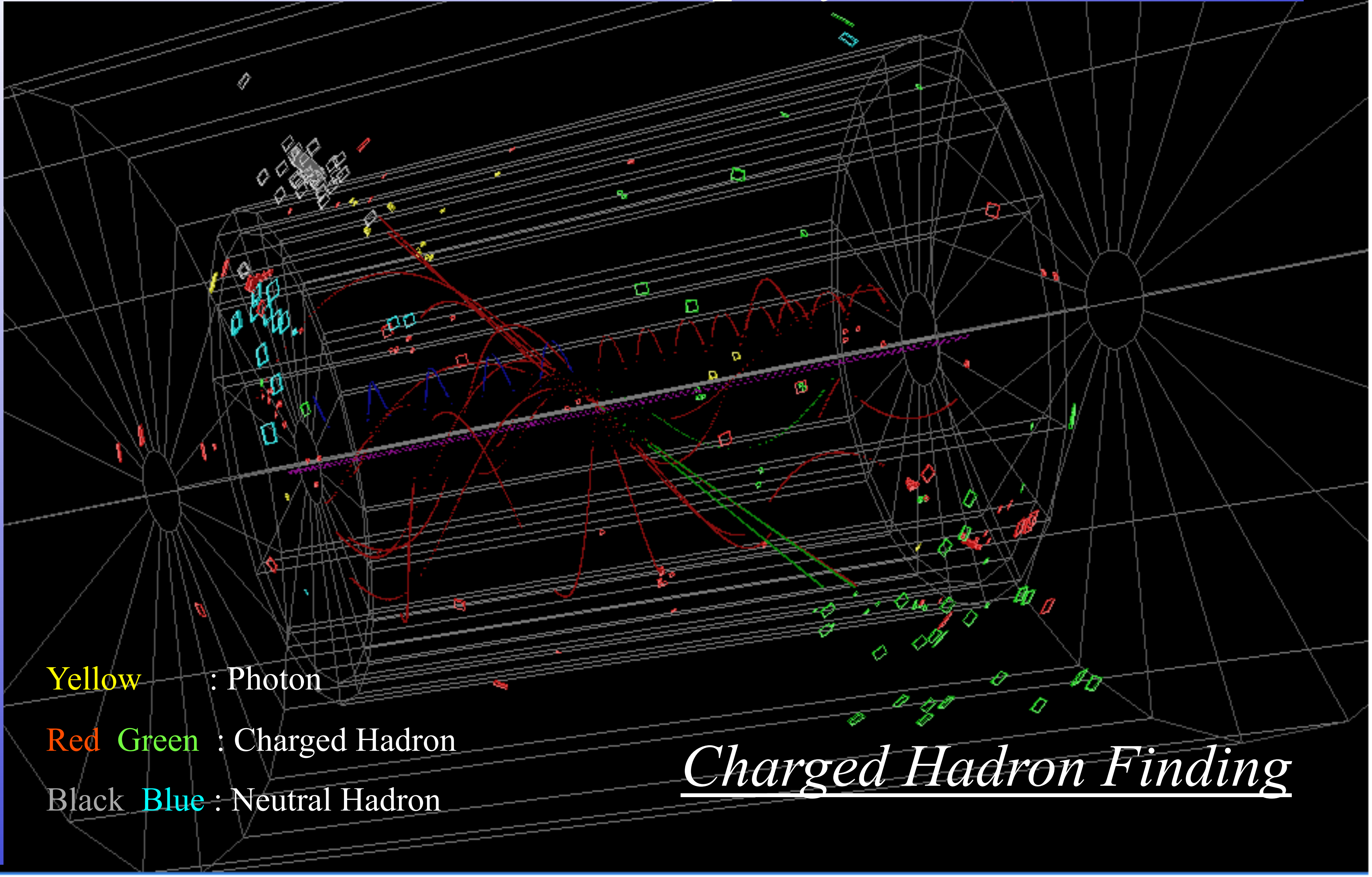
Black Blue : Neutral Hadron

Gamma Finding

PFA

Event Display

T. Yoshioka



Yellow : Photon

Red Green : Charged Hadron

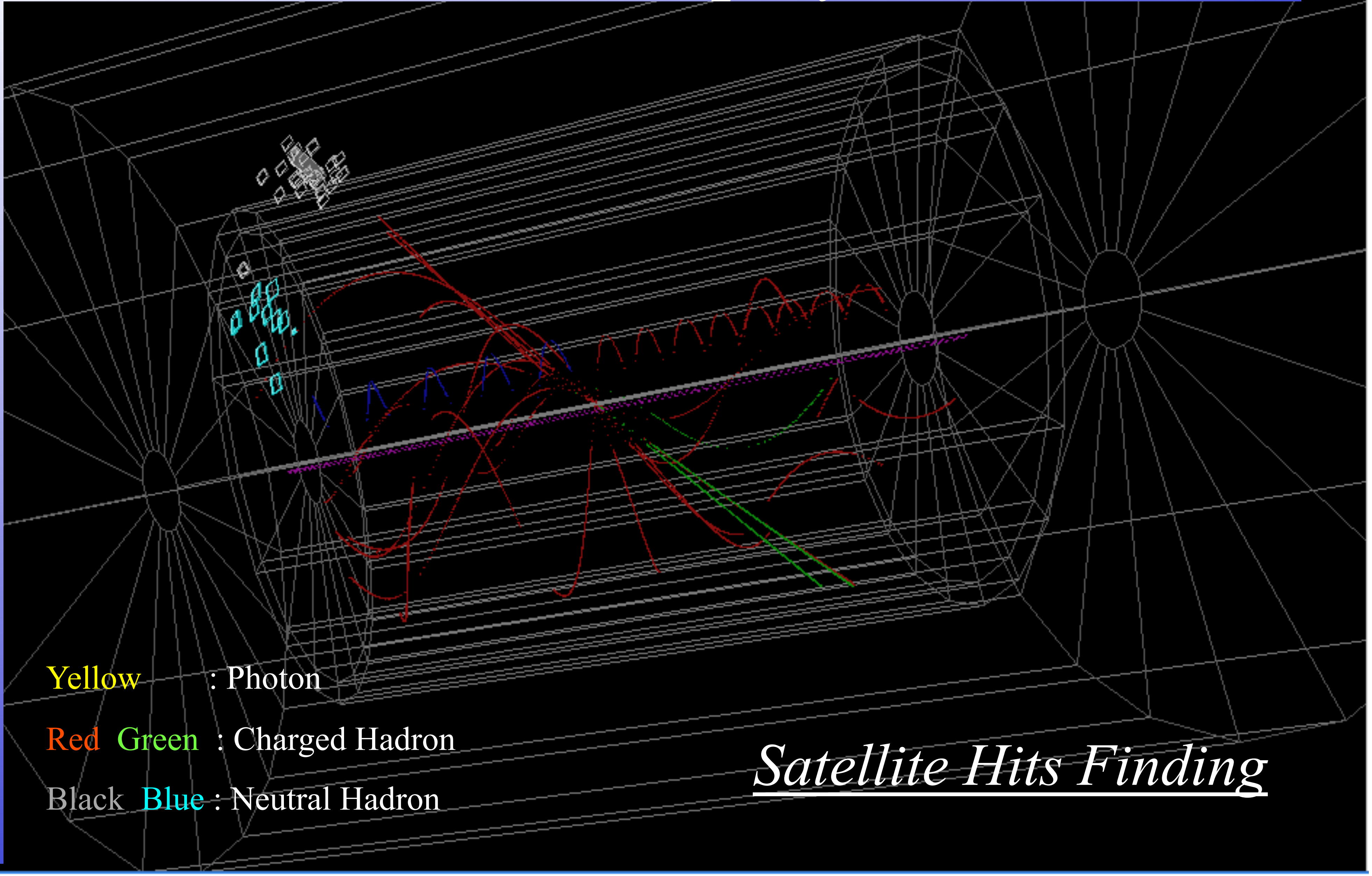
Black Blue : Neutral Hadron

Charged Hadron Finding

PFA

T. Yoshioka

Event Display



Yellow : Photon

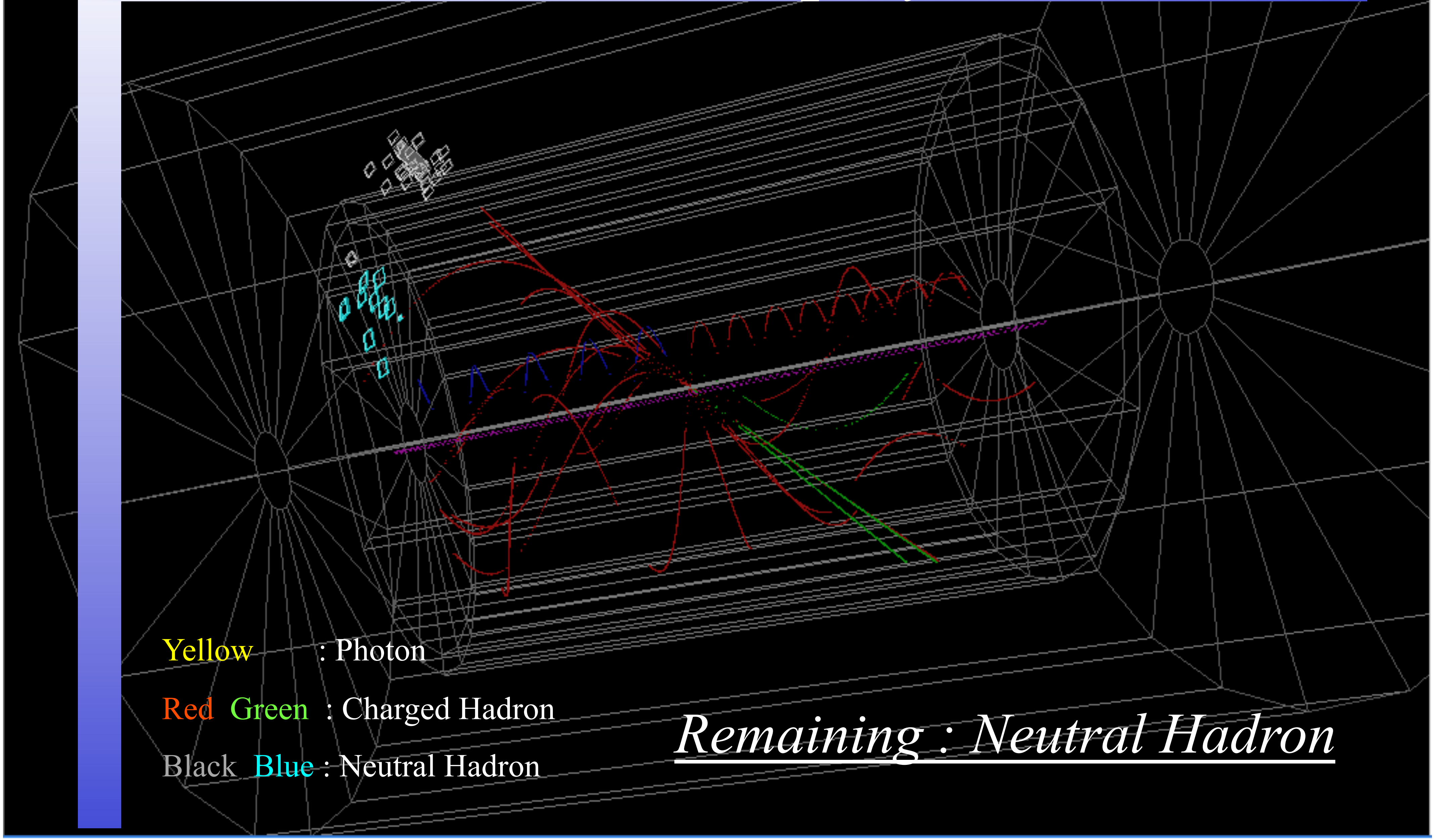
Red Green : Charged Hadron

Black Blue : Neutral Hadron

Satellite Hits Finding

Event Display

T. Yoshioka



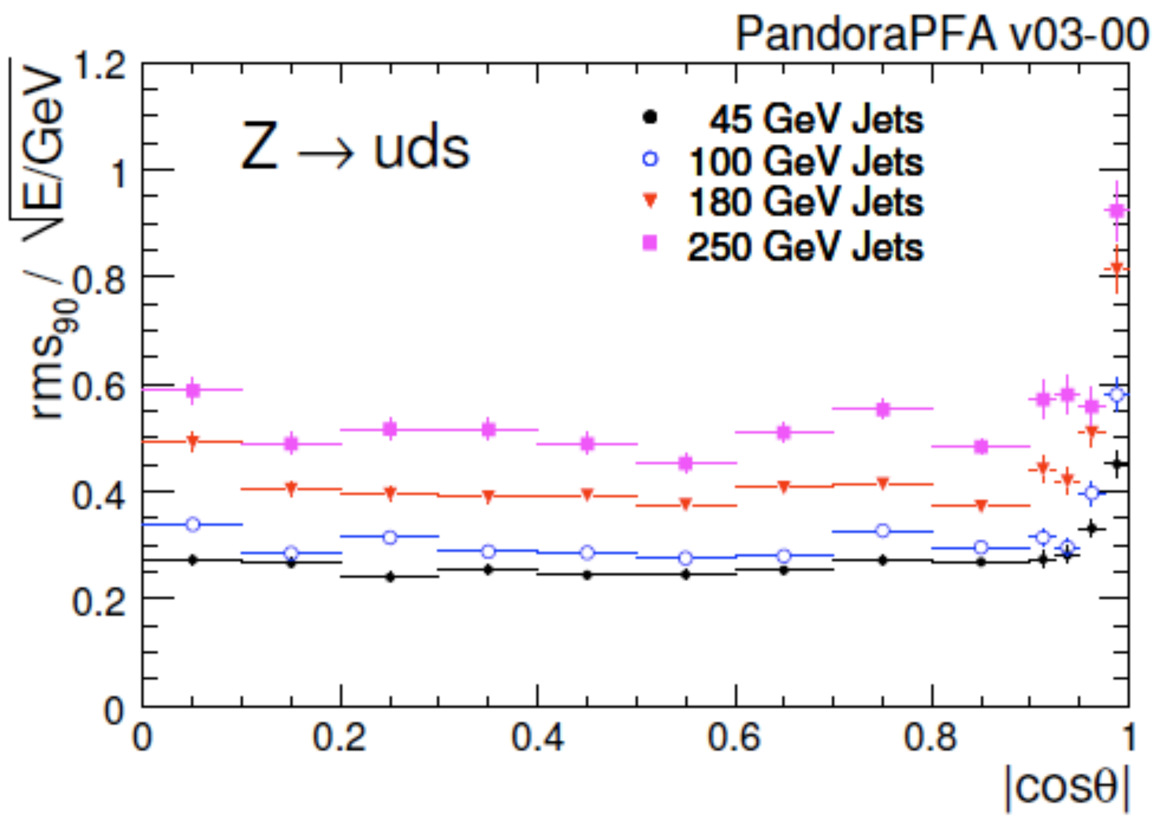
Yellow : Photon

Red Green : Charged Hadron

Black Blue : Neutral Hadron

Remaining : Neutral Hadron

PFA Performance - state of the art -



Realistic full simulation (ILD)
Achieved $\sigma_E / E = 0.3/\sqrt{E}$ at Ejet up to ~100 GeV

ILC Detectors

	ILD	SiD	4th
Tracker	TPC+Si-strip	Si-strip	TPC/Si-strip/DC
Calorimeter	PFA	PFA	Compensating
B	3.5 T	5T	3.5T
ECAL Rin	1.83m	1.25m	1.5m
Rout	6.99m	6.20m	5.80m
Zout	6.62m	5.60m	6.08m

(dimensions are approximate)

3 groups submitted LOI:
http://www.linearcollider.org/cms/?pid=1000472

All: ECAL/HCAL inside solenoid
Uses pixel detectors for vertexing

IDAG Validation

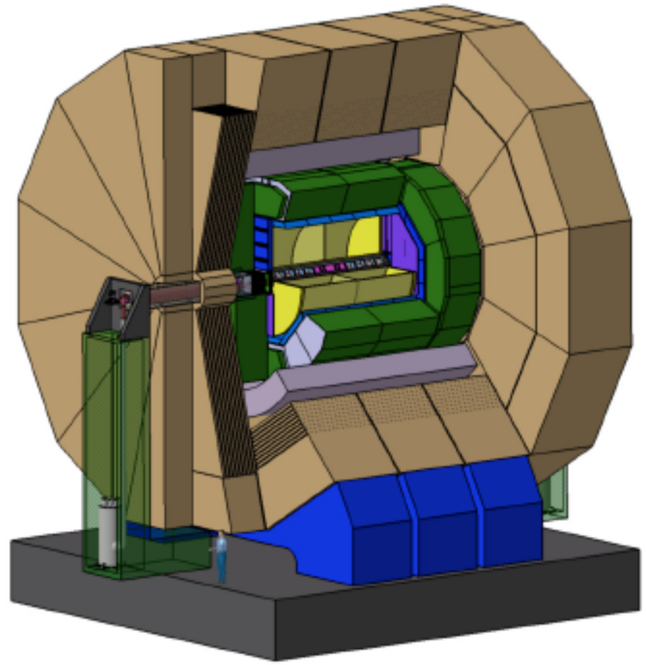
- IDAG (International Detector Advisory Group)
  - Advises the research director of ILC
  - Evaluated the LOIs that are submitted March 31, 2009, and reported its recommendation to the research director

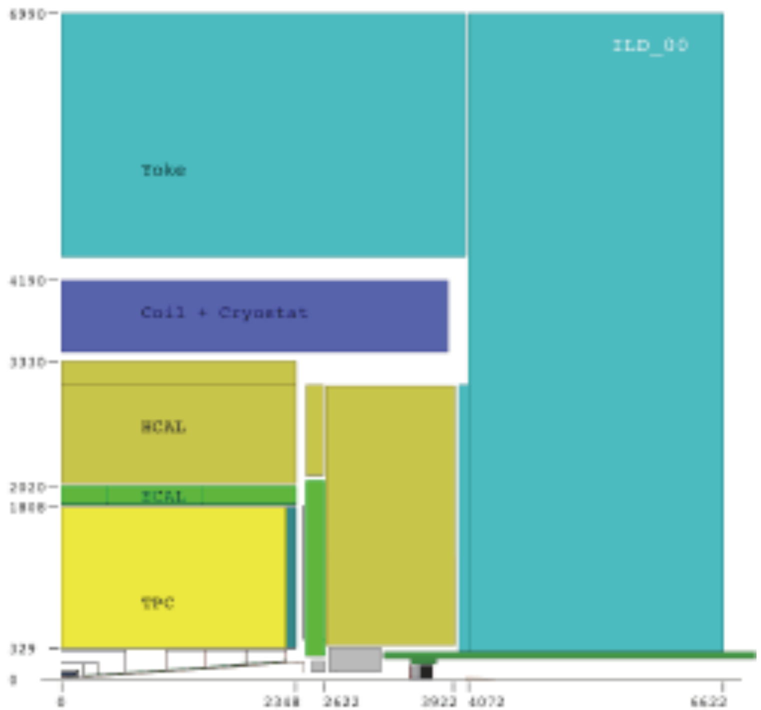
- ILCSC approved the recommendation, Aug 19, 2009.

- The validation result officially announced at ALCPG09 (Albuquerque, Sep 29. 2009)
  - ILD and SiD are 'validated' (i.e. endorsed to work toward the 2012 detailed baseline report.)
  - Dual-readout calorimetry R&Ds are encouraged to continue
  - Ref: http://www.linearcollider.org/cms/?pid=1000471

ILD

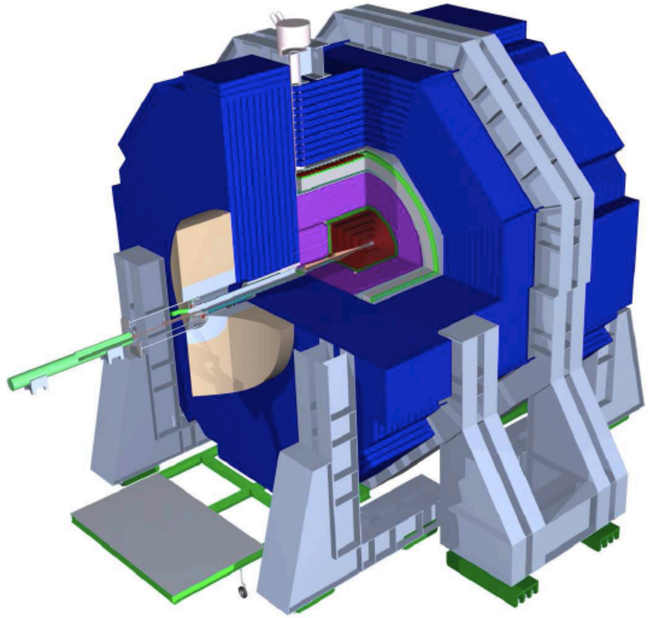
- Vertex
  - 6 (3 pairs) or 5 layers (no disks)
  - Technology open
- Si-strip trackers
  - 2 barrel + 7 forward disks (3 of the disks are pixel)
  - Outer and end of TPC
- TPC
  - GEM or MicroMEGAS
  - Pad (or si-pixel) readout
- ECAL
  - Si-W or Scint-strip-W
- HCAL
  - Scint-tile or Digital HCAL

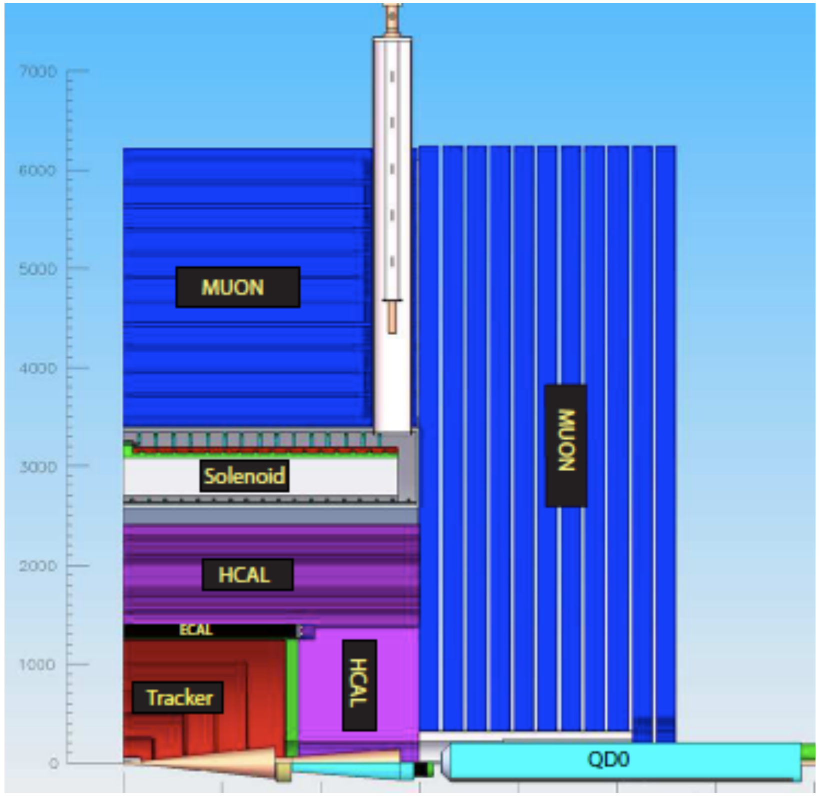




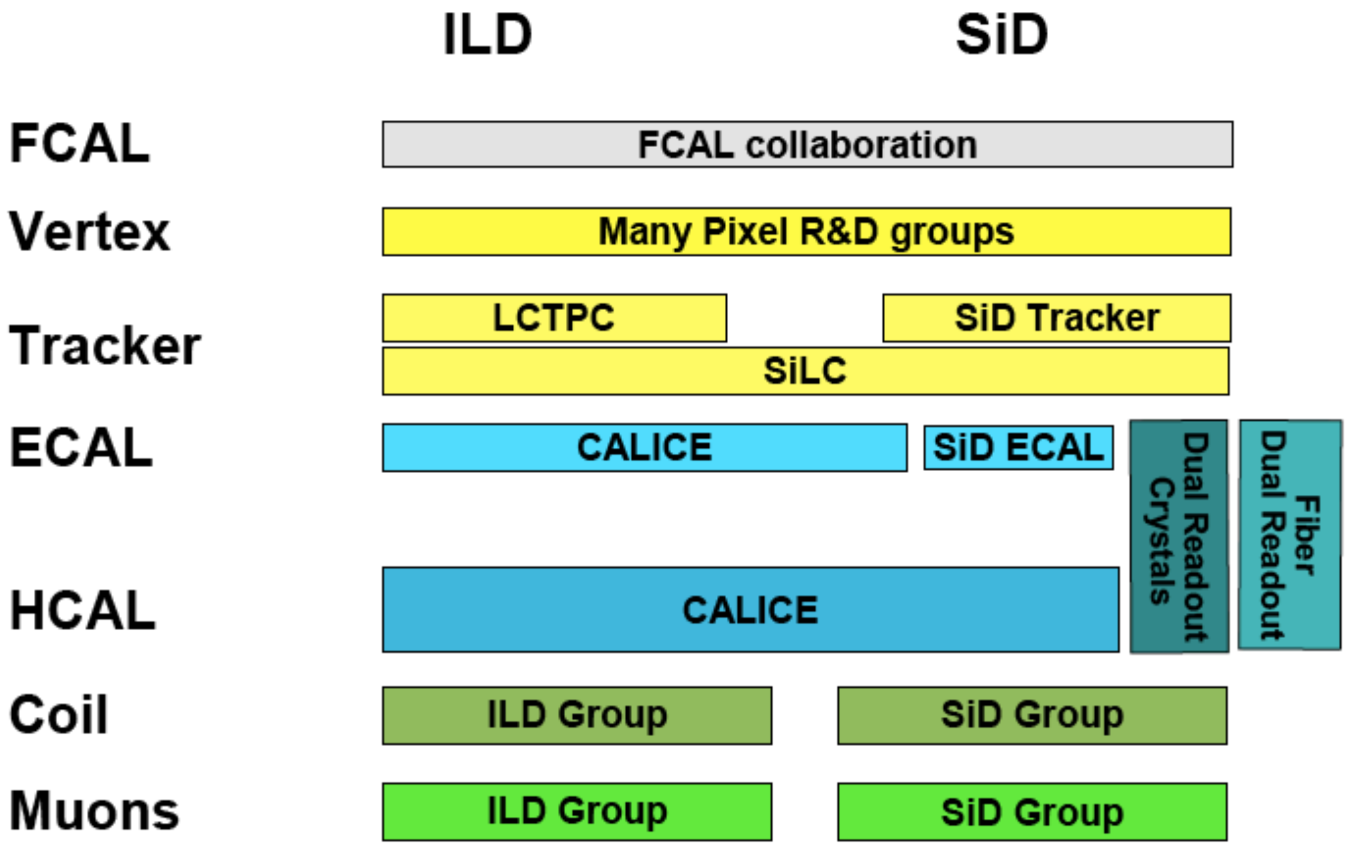
SiD

- Vertex
  - 5 barrel lyrs + 4 disks
  - Technology open
- Si-strip-trackers
  - 5 barrel lyrs + 4 forward disks/ side
- EMCAL
  - Si-W 30 lyrs, pixel $(4\text{mm})^2$
- HCAL
  - Digital HCAL with RPC readout with $(1\text{cm})^2$ cell
  - 40 lyrs





ILC Detector R&D Groups



Marcel Stanitzki

Driven by 'horizontal' collaborations

WWS Reviews on ILC Detector R&Ds

- Goal
  - Improved communications → enhanced R&Ds
- Reviewers
  - WWS R&D panel members, external experts, funding agency reps. Chair: C. Damerell
- Had 3 reviews:
  - Feb 07, Beijing : Tracking
  - Jun 07 DESY : Calorimetry
  - Oct 07 Fermilab : Vertexing
- Reports
  - http://physics.uoregon.edu/~lc/wwstudy/detrdrev.html
  - Valuable information on ILC-related detector R&Ds

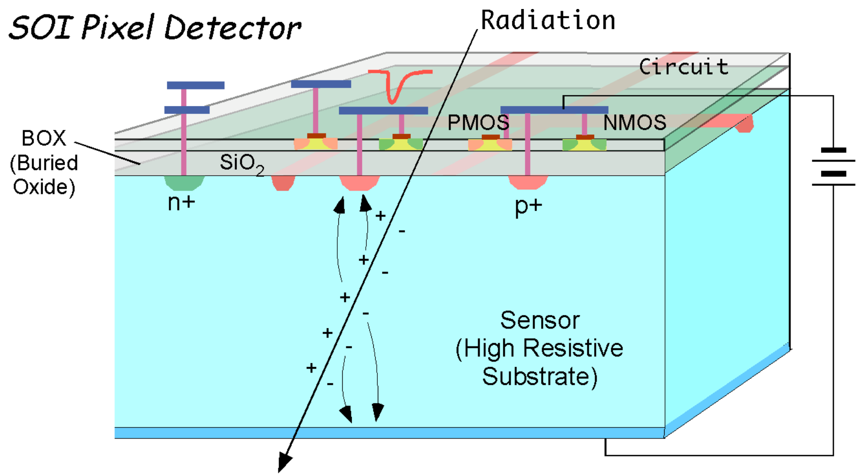
The WWS R&D panel is superseded by the R&D common task group chaired by M. Demarteau (under the ILC research director)

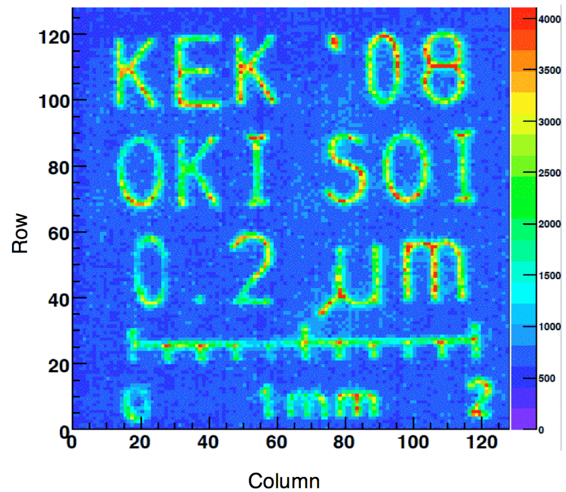
Vertexing

- If one integrates hits over 1 train for $(25\ \mu m)^2$ pixel,
  - Occupancy too high (by the pair background)
  - Strategies: time slice a train (~20), small pixel, bunch id (ideal)
- Many technological options pursued:
  - Time slicing: CPCCD, ISIS, MAPS, deep N-well, CAP, DEPFET
  - Small pixel: FPCCD
  - Bunch id: Chronopixels, SOI, 3D
- Vertexing Review Report
  - 'Unable to eliminate any of them (at present)'
  - '2-4 technologies to start up, others for upgrades'
  - 'Some have applications in other fields'
- Promising technologies: vertical integration (3D, SOI)

SOI (Silicon on Insulator)

- Semi vertical integration
- Active area very close to the readout circuit (~200nm)
  - Sensor interferes with the readout circuit (e.g. back gate effect)
- Buried p-well technology:
  - Fixed the back-gate effect
  - A major advance for SOI





3D Integration

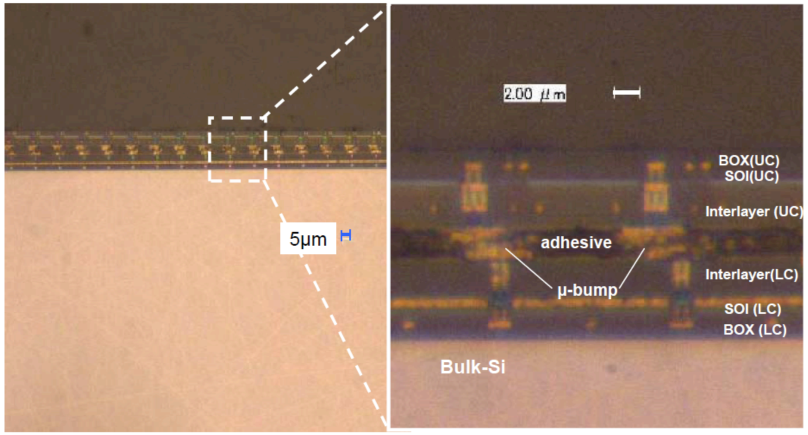
- Via and bonding technologies
  - industry-driven
- Liberation from the process constraints
- Higher integration density
- Radiation tolerance
- Lower power consumption

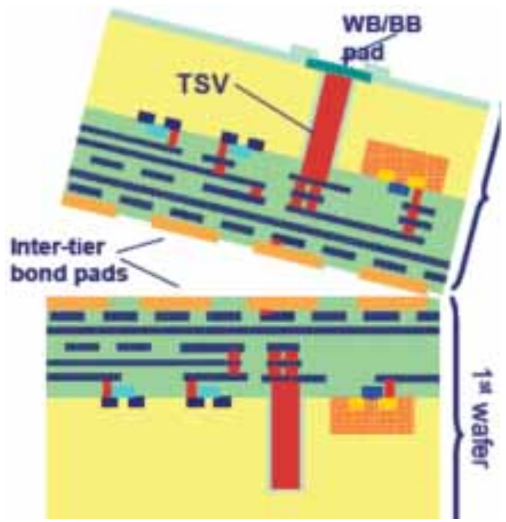
● Zycube (bonding)
Test chip designed by
LBNL/KEK made by OKI
Being tested now

● Terrazon run.
FNAL-based.
Broad range of MAPS and readout
Electronics, being fabricated now

● More to come

Zycube





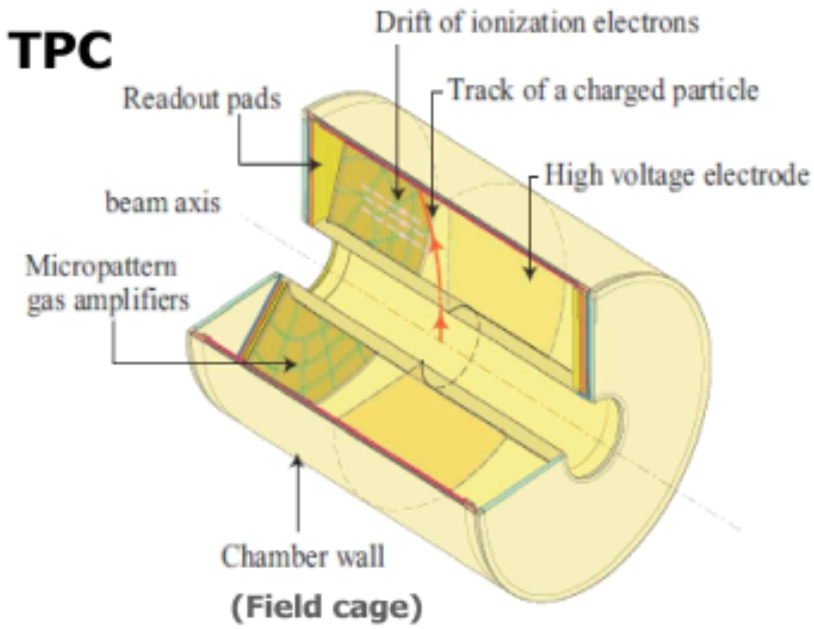
Main Tracker

- 3 basic technologies
  - Si strip (SiLC collaboration, SiD tracker)
  - TPC (LC-TPC collaboration)
  - CluCou (cluster-counting DC for 4th)
- WWS review panel report
  - 'Extremely impressed'
  - 'Currently far from goals for all options'
  - 'Forward tracking' : 'achieved in practice?'
  - 'A large prototype (R=1m) in B=3~5 T recommended'

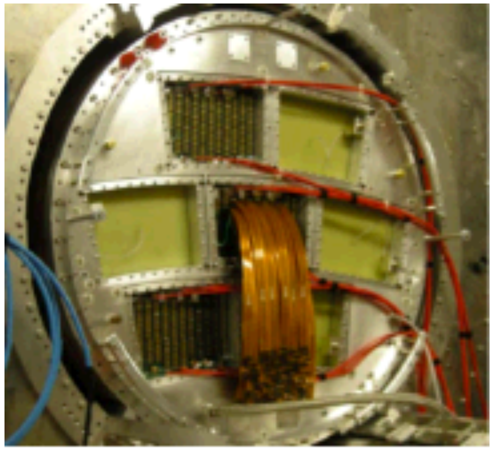
    Not yet: LC-TPC has tested a 'large-prototype' with r=38cm in 1T

LC-TPC collaboration

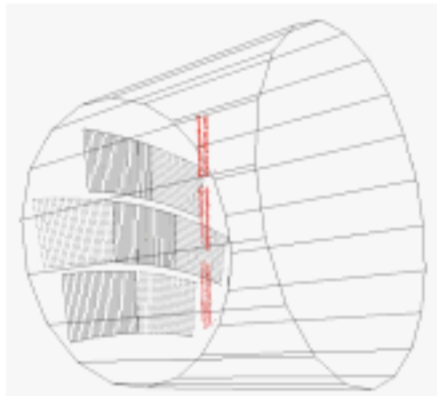
- Goal: develop ILD TPC
    - ~200 points per track
    - R = 1.8m, L=4.3m
    - MPGD
        – GEM or MicroMEGAS
    - Read out
        – 1x5 mm^2 pads
        – CMOS pixel option under R&D
- ‘Large’ prototype made
    – D = 0.7m, L=0.6m
    – Beam test under 1T (DESY)
    – Both GEM and MicroMEGAS
    – So far so good. Data is being analyzed.



Prototype endplate



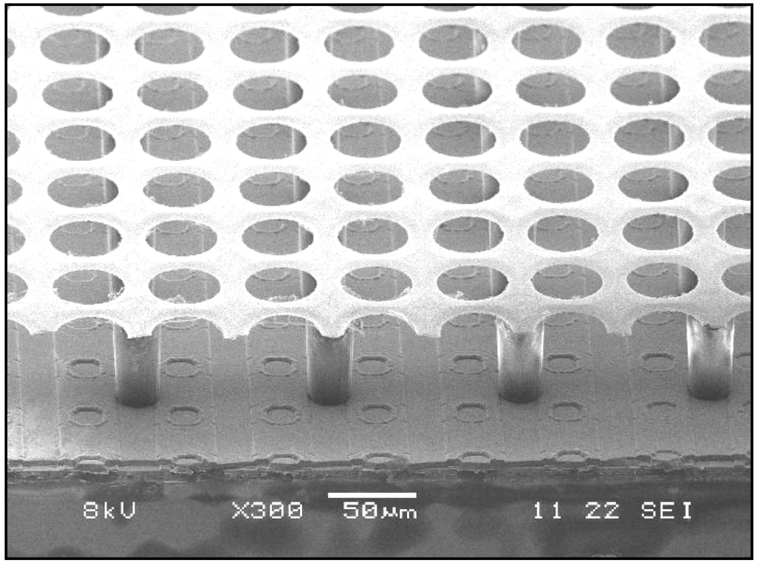
Beam with GEM

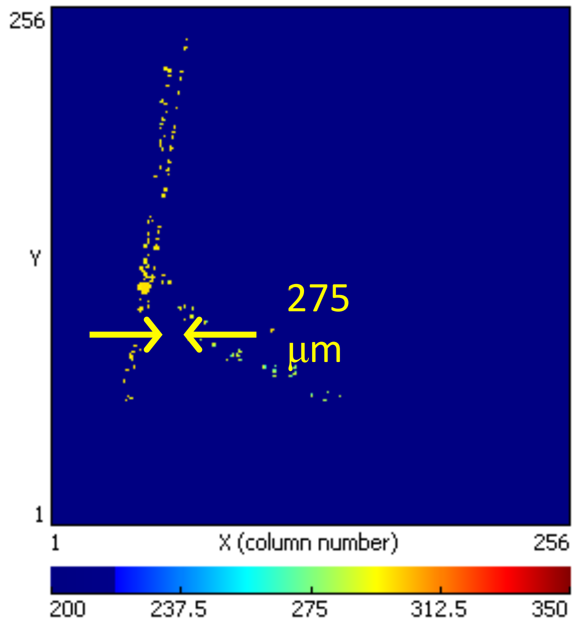


Pixel Readout of TPC

Use pixel sensors instead of pads
Cell size : 1x5 mm^2 → 55x55 μm^2

Good spacial resolution
Good 2-track separation (<1mm)
Possibly cluster counting (dE/dx)





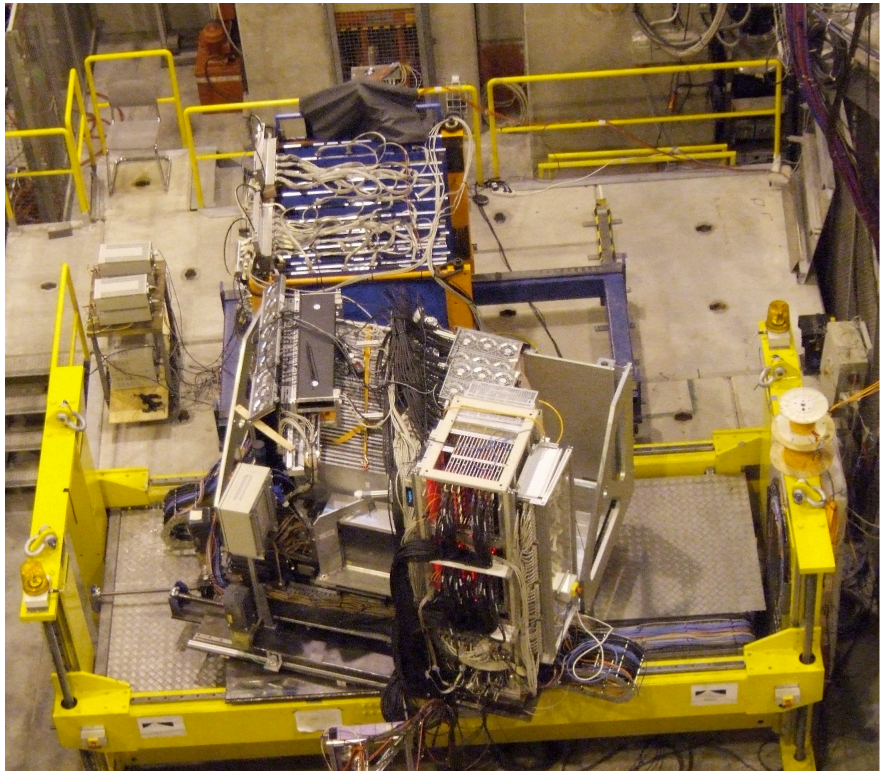
Calorimetry

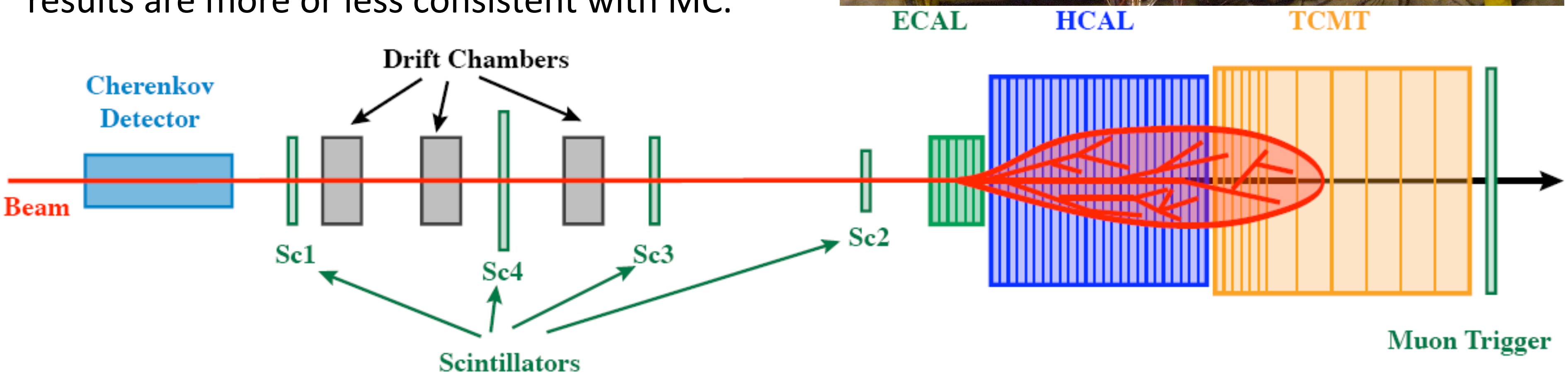
- PFA-based
  - CALICE collaboration (41 groups)
    - Si-W and Scint-W ECAL, Analog and DigitalHCAL
  - SiD-CAL (17 groups, some in CALICE)
    - Si-W ECAL, DHCAL, AnalogHCAL
- Compensating (dual-readout)
  - DREAM collaboration (8 groups)
  - Fermilab group
- WWS review panel report
  - ‘PFA and compensating both may be needed – esp. in forward region’
  - Compensating:
    - ‘Needs more people’, ‘The approach could be the outright winner particularly in the … forward region’
  - PFA:
    - ‘Extremely promising, but simulation alone cannot be trusted.’
    - ‘Use a large-scale physics prototypes’
      – cal part nearly done (CALICE) (tracking not included)

CALICE Beam Tests

- Main beam tests, using π, μ, e beams:
- 2006-7
  - SiW ECAL + AHCAL + TCMT @ CERN
- 2007
  - Small DHCAL test @ Fermilab
- 2008
  - SiW ECAL + AHCAL + TCMT @ Fermilab
- 2009
  - Scint-W ECAL + AHCAL + TCMT @ Fermilab
  - Standalone RPC and Micromegas tests @ CERN
- 2010 planned
  - SiW ECAL + DHCAL + TCMT @ Fermilab

There is no perfect Hadron shower MC, but results are more or less consistent with MC.



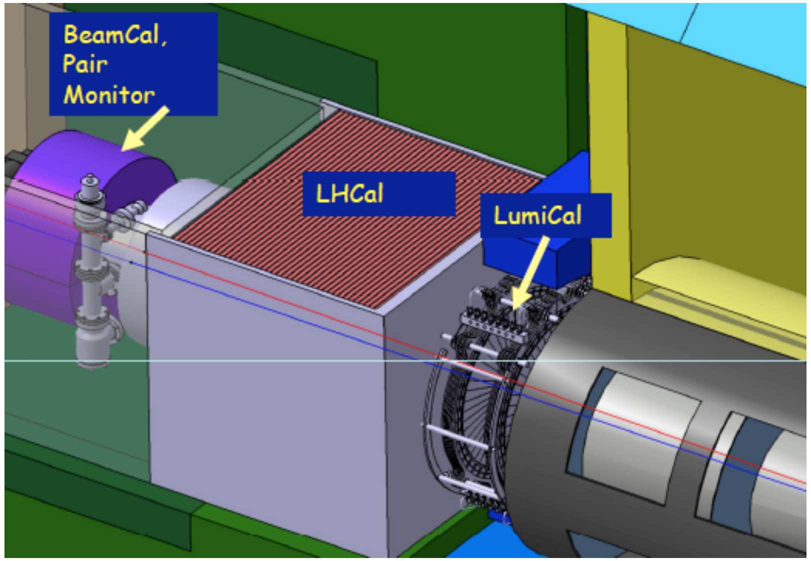


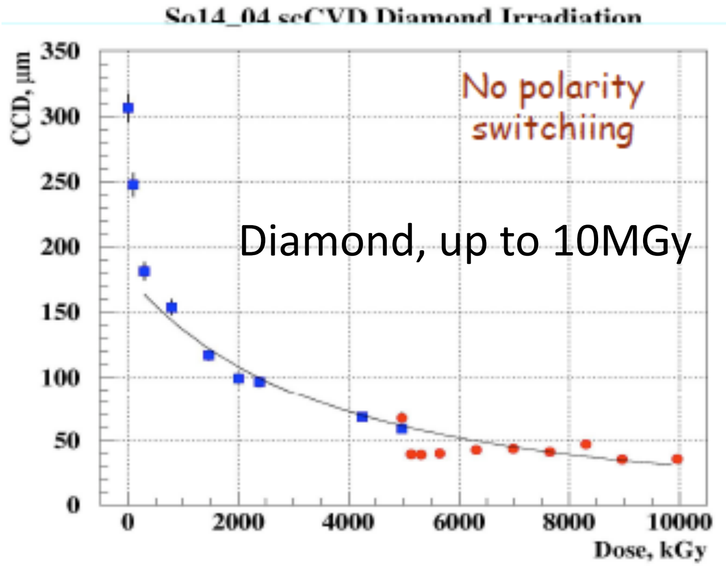
Forward Instrumentation

ILD

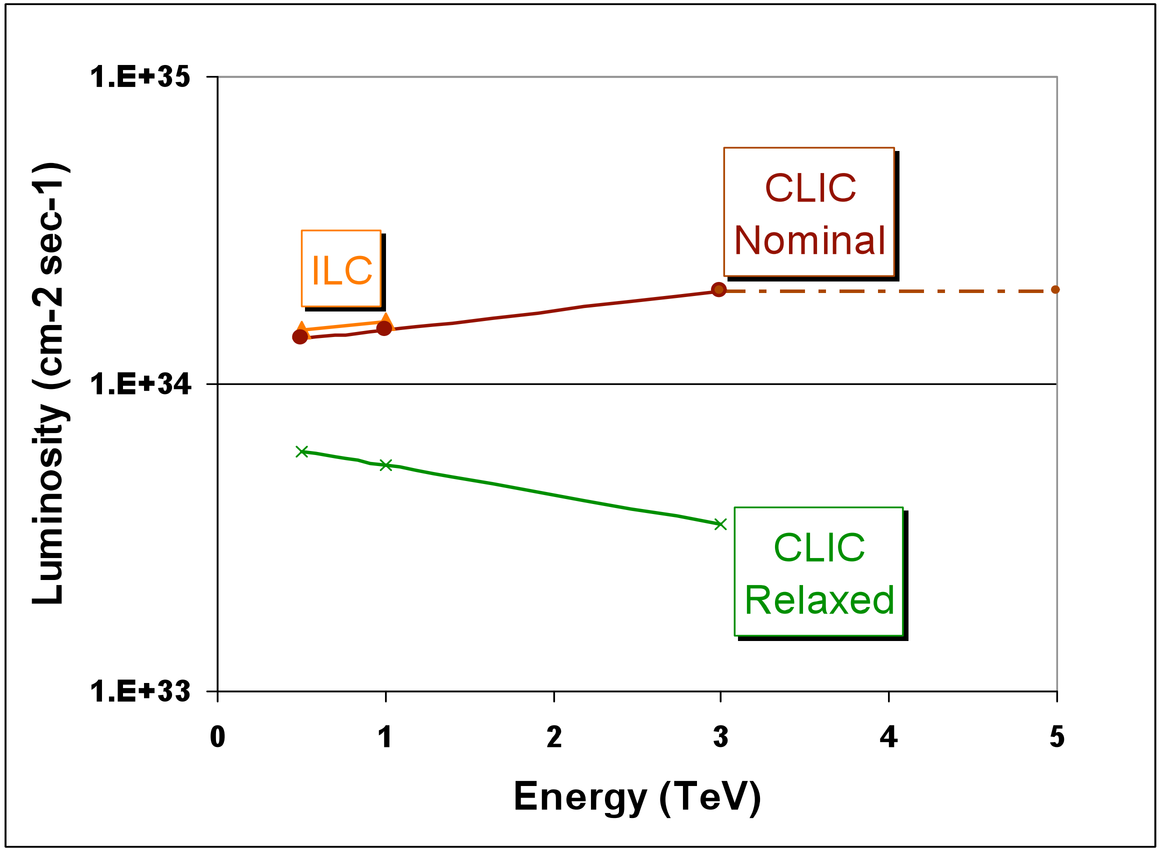
FCAL collaboration

- BeamCAL
  - GaAs
  - Diamond (sCVD)
  - Sapphire
- LumiCAL
  - Short Si-strip
- Pair monitor
  - Si pixel
- Applications
  - FLASH, CMS - tested





CLIC



1.E+35
1.E+34
1.E+33
Luminosity (cm-2 sec-1)
0
1
2
3
4
5
Energy (TeV)
ILC
CLIC Nominal
CLIC Relaxed

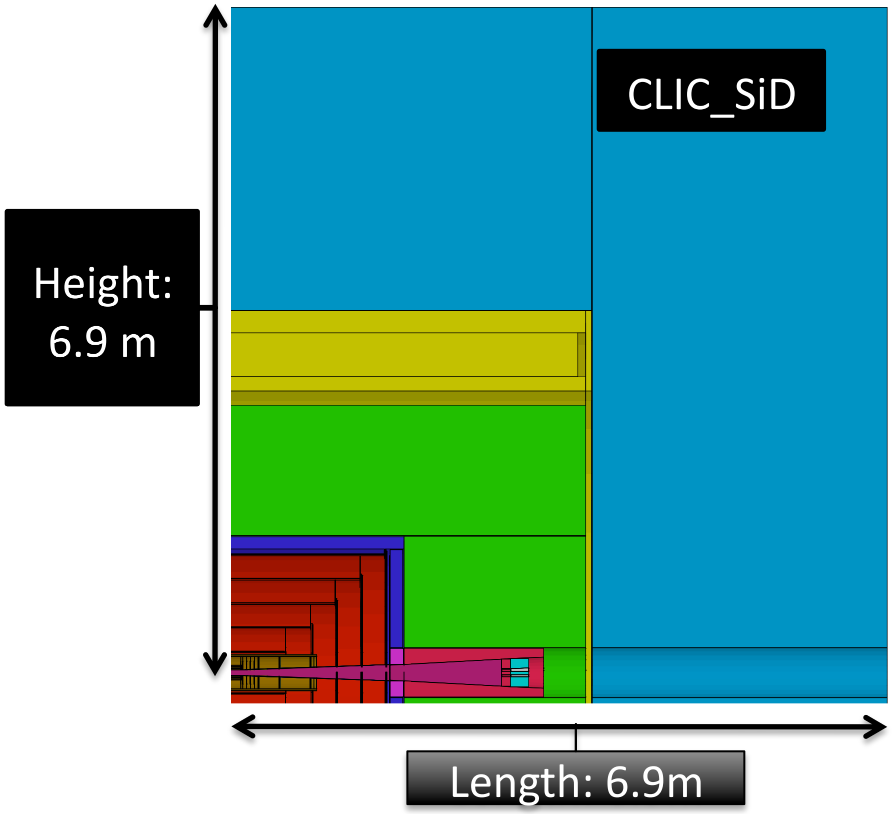
Andre Sailer

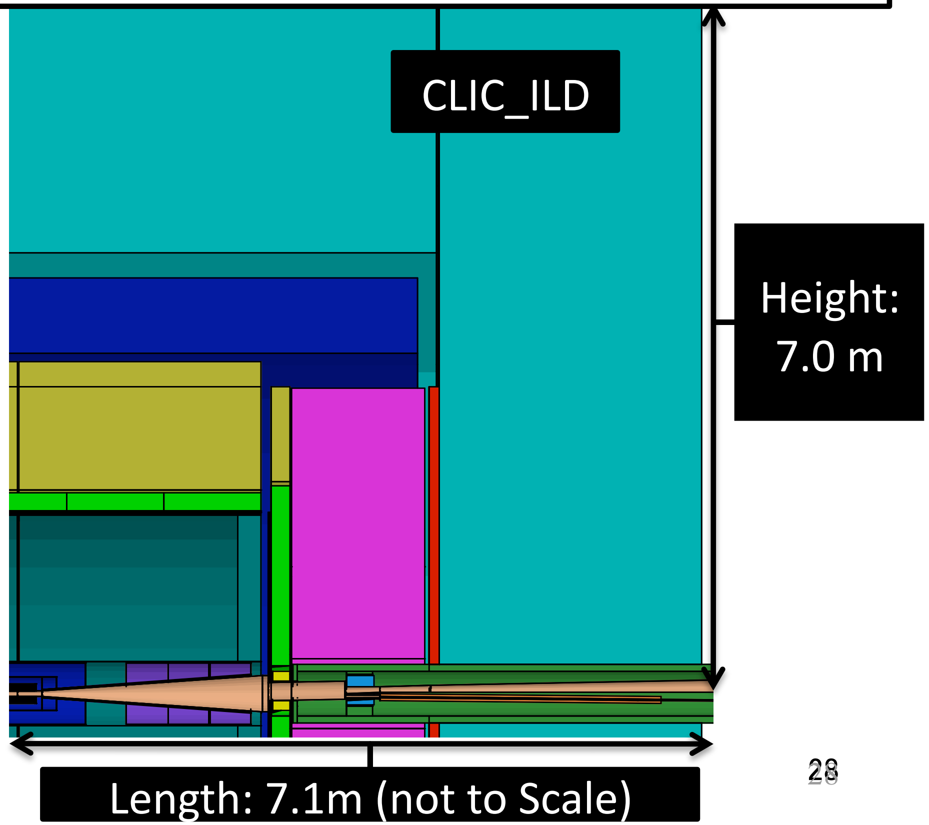
From ILC to CLIC Detectors

- Created CLIC 3 TeV detector models using SiD and ILD geometries and software

Changes:

- 20 mrad crossing angle (instead of 14 mrad)
- Vertex Detector to ~30 mm inner radius, due to Beam-Beam Background
- Hadron Calorimeter, more dense and deeper ($7.5\ \lambda_i$) due to higher energetic Jets
- For CLIC_SiD: Moved Coil to 2.9m (CMS Like)





Pair Backgrounds

CLIC 3 TeV :

Coherent pairs (3.8×10^{8} per bunch crossing)
High energy (~ TeV) → disappear in beam pipe : ignore for now

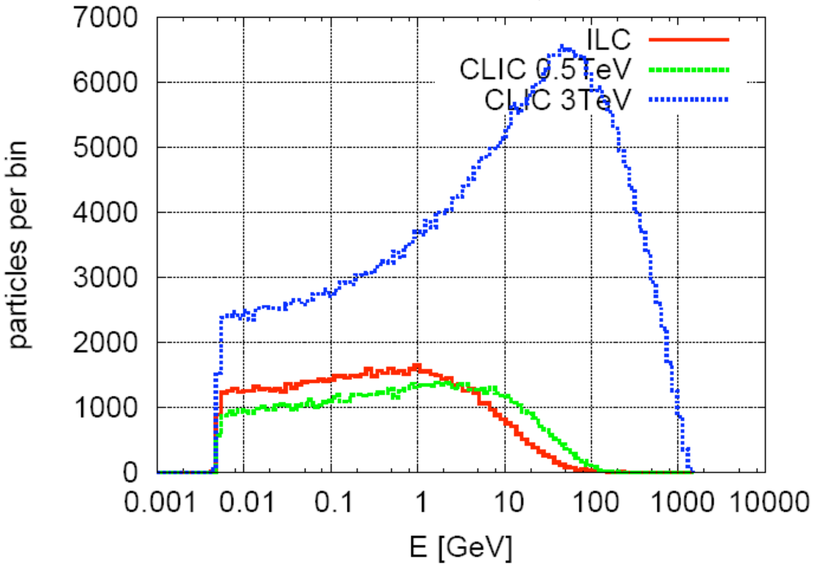
Incoherent pairs (3.0×10^{5} per bunch crossing)
Lower energy → inner vertex layers

Incoherent pairs:
ILC 0.5 TeV: n_{incoh} 0.1×10^{6} bx
CLIC 3 TeV: n_{incoh} 0.3×10^{6} bx

Large energy diffrence between 0.5 TeV and 3 TeV.

Pt of pairs: x3 for CLIC 3 TeV wrt ILC

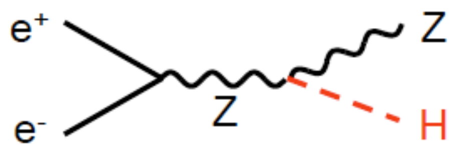
B. Dalena, D. Schulte



S vs T channel

S-channel

e.g.

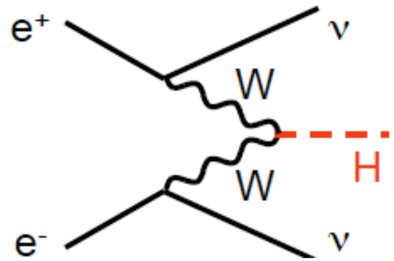


Cross section ∝ 1/S
decreases with S

Particles → barrel region

T-channel

e.g.



Cross section ∝ log S
increases with S

Particles → forward region

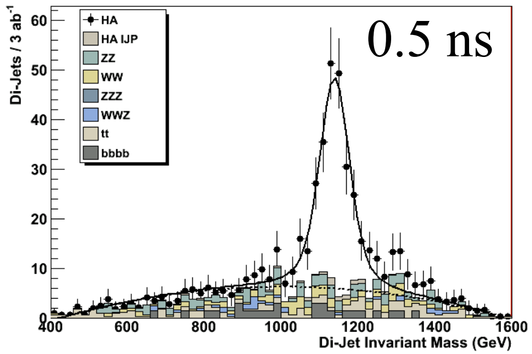
At high energy (3 TeV), T-channel processes tend to dominate.

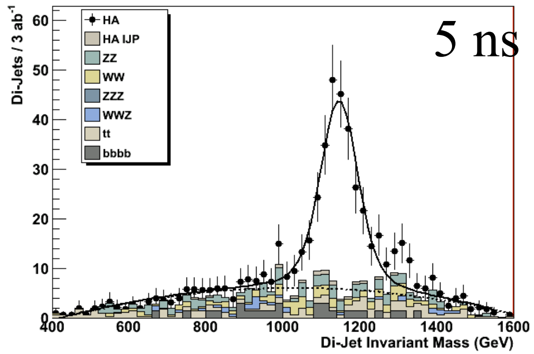
Lots of backgrounds in forward region
- esp. 2γ → hadrons.

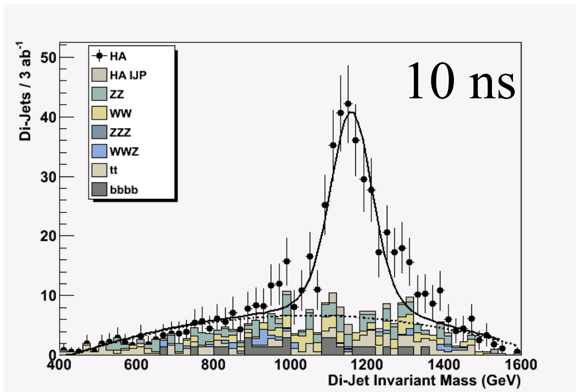
Time Stamping

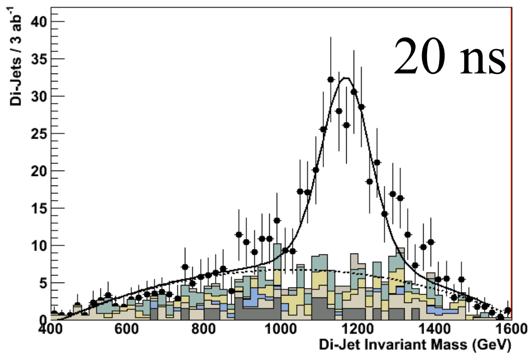
Energy in e^+e^- event from $\gamma\gamma \rightarrow$ hadrons background

Degradation of physics signal as function of background integrated in the detector
(MOKKA G4 Simulation + Marlin Reconstruction)









Preliminary results of full G4+reco analyses indicate physics performance impacted for Δt > 10-15 ns

M. Battaglia

Time Stamping in Vertexing

At preset: no proven/usable technology to achieve 10ns time stamping with small enough pixel (<25 μm sq.)

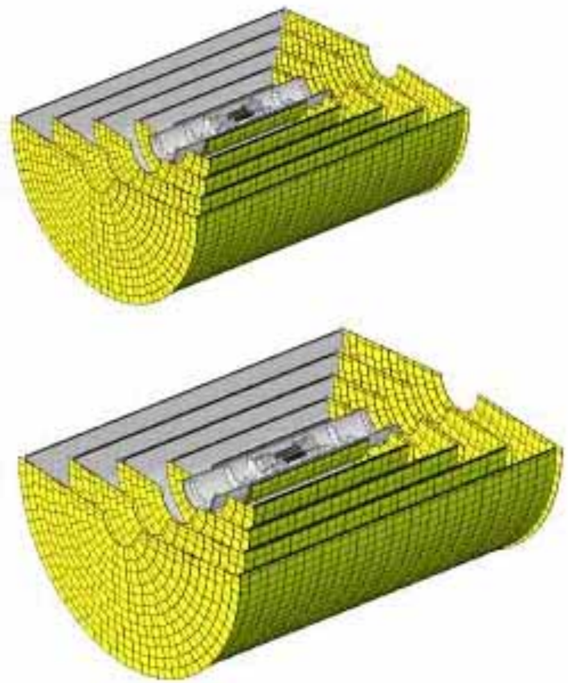
H.G. Moser: (CLIC09)

Hybrid Pixels (LHC-like): too much material, large pixels
CMOS Sensors: too slow
DEPFET: too slow (frame readout)

Advanced CMOS: very interesting. Key: PMOS & high resistivity epi

3D integration: solves many problems:
evolution/combination of hybrid pixels, MAPS or DEPFETs
$\Rightarrow$Most promising way to go!

Tracker : Silicon vs TPC



Silicon Tracker

Possibly good for time stamping.

Maybe also better suited for forward region Tracking. (no thick end-plate)

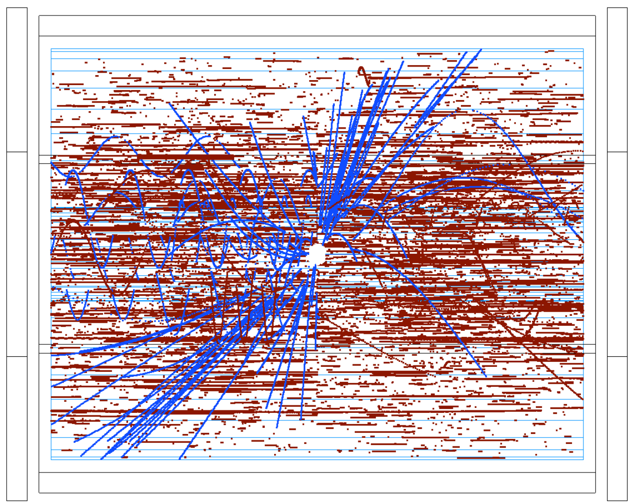
Can pattern recognition work in the high background environment?

TPC

50 μs full drift,

Salt-and pepper backgrounds are mostly removed by rejecting micro-curlers. No significant efficiency loss at ILC.

Can it still work at CLIC? (short bunch sp., more bkg)



Forward Tracking

Marcel Vos

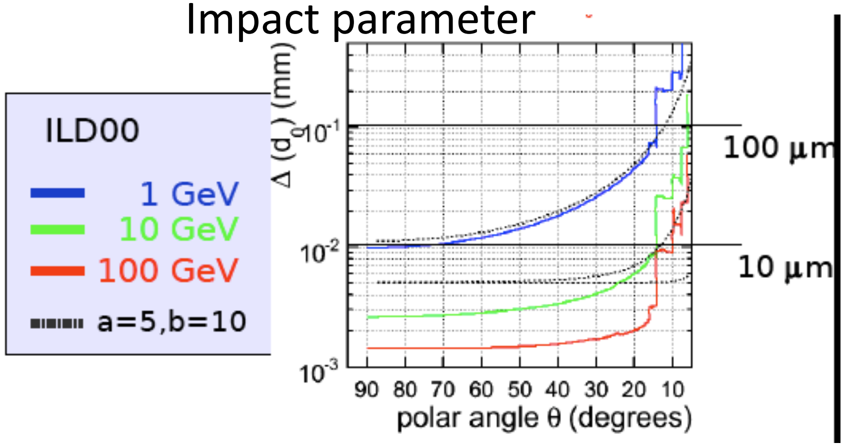
Conslusion:

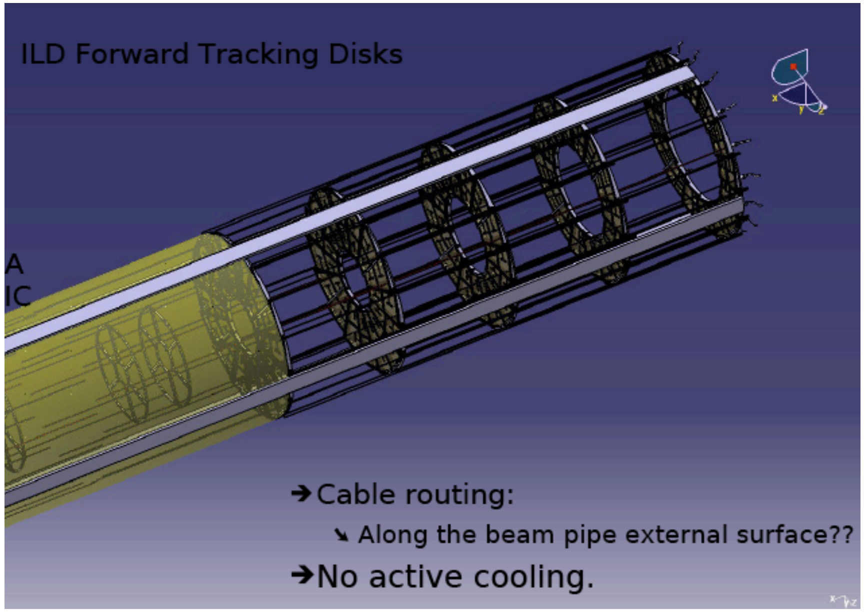
If the central tracking and vertexing is semewhat of a challenge (for CLIC), maintaining good performance at small polar angle is close to impossibility.

- Backgrounds
- Momentum resolution (B field)
- Vertexing (Barrel servicing)
- Pattern recognition

Clearly, needs intensive work.

Impact parameter



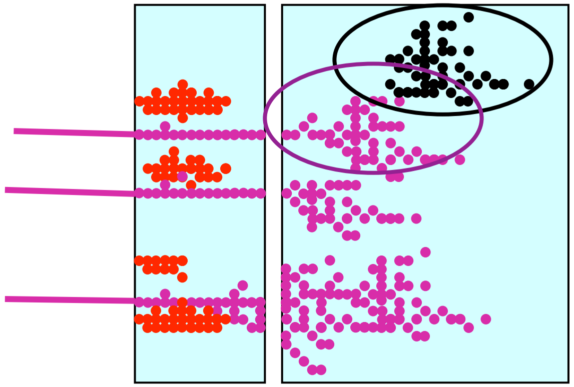


Jet reconstruction - PFA (Pandra)

B = 4 T (3.5 T for ILD)
HCAL : 8 λ (6 λ for ILD)

Meets the jet energy resolution goal (3~4%) up to 500 GeV jet.

SiD PFA and Compensating Calorimetry give similar jet resolution



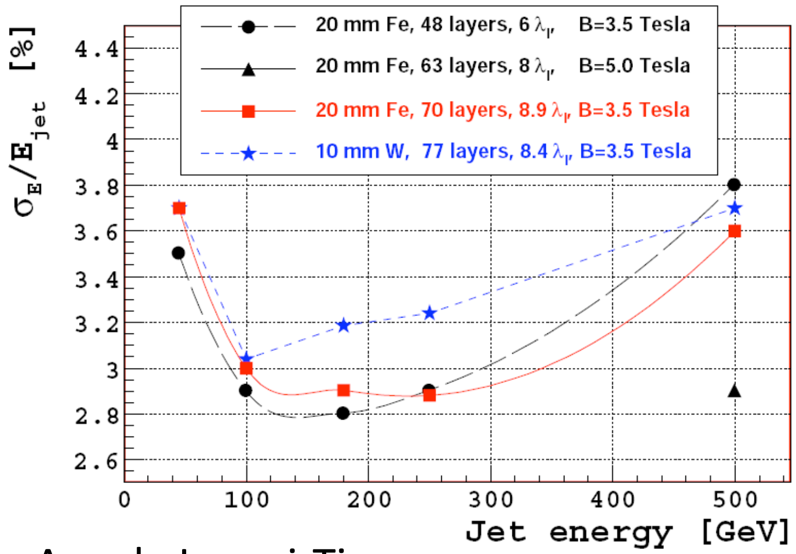
M. Thomson

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ |cosθ|<0.7	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	28.7 %	2.9 %
180 GeV	37.5 %	2.8 %
250 GeV	44.7 %	2.8 %
375 GeV	71.7 %	3.2 %
500 GeV	78.0 %	3.5 %

W-HCAL

Simulation :
(P. Speckmayer)

PFA resolution is comparable to Fe
- No tuning done for W



Angela Lucaci-Timoce

Prototype idea:
(W. Klempt)

Start 2010 with a "small" prototype:

*Start with ~20 W plates size 80x80 cm^2, 1 cm thick

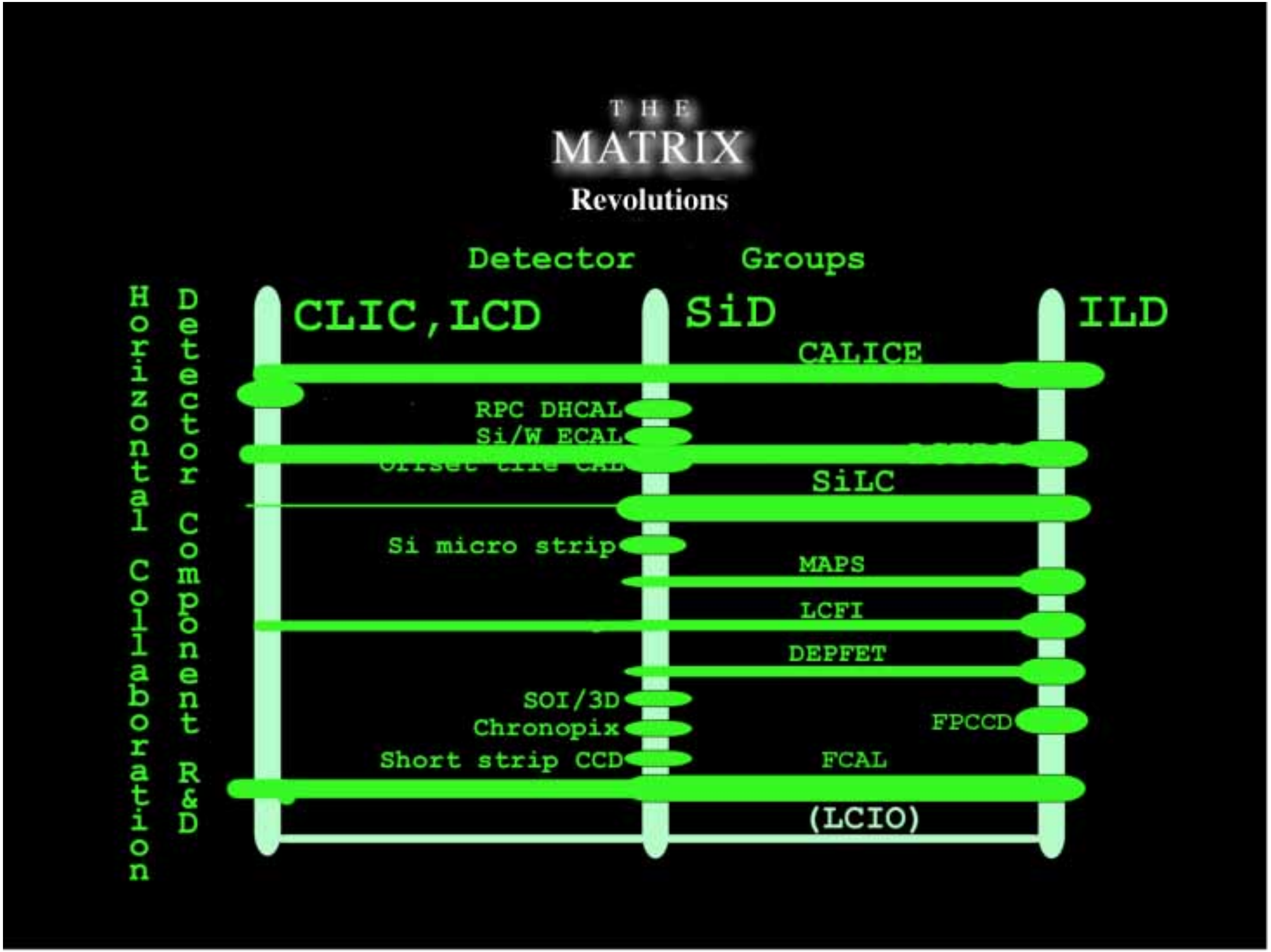
*Use as much as possible existing equipment from CALICE (detector planes, readout electronics, DAQ, mechanical infrastructure…..)

*First test beam at PS/SPS in autumn 2010

*Later increase depth to 40 or more layers

Summary

- Much of the HEP detector R&Ds have been driven by ILC
  - Horizontal detector R&D collborations have been effective in carrying out the efforts. (CALICE, LC-TPC, SiLC, FCAL, etc…)
- The large amount of works done for ILC detectors are concisely summarized in the 3 LOIs:
  - http://www.linearcollider.org/cms/?pid=1000472
- Critical assessments of the ILC detector R&Ds are reported in the WWS detector R&D reviews:
  - http://physics.uoregon.edu/~lc/wwstudy/detrdrev.html
- CLIC detector R&Ds have greatly benefitted from the ILC detector studies.
- There are important 'CLIC-specific' issues, but solutions to them will benefit ILC.
  - Time stamping, forward region, etc.


THE
MATRIX
Revolutions
Detector Groups
CLIC,LCD
SiD
ILD
Horizontal Collaboration
Detector Component R&D
CALICE
RPC DHCAL
Si/W ECAL
SiLC
Si micro strip
MAPS
LCFI
DEPFET
SOI/3D
Chronopix
FPCCD
Short strip CCD
FCAL
(LCIO)